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TECHNICAL NOTE ON THE CONSTRUCTION OF STOPPINGS OR DAMS IN THE SYDNEY COALFIELD

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TECHNICAL NOTE ON THE CONSTRUCTION OF STOPPINGS OR DAMS IN THE SYDNEY COALFIELD

by

G.A. Haslett*

ABSTRACT

This technical note reviews briefly the reasons for which stoppings or dams are constructed.

For whatever reasons stoppings or dams are constructed within underground coal mines, it argues that the only acceptable standards of construction are those of adequacy against any explosion that might occur behind any stopping or dam within those sealed off workings that are no longer accessible. Any stopping or dam must also exclude (seal off) the migration of any air or other gases from behind the stopping (dam) into the general atmosphere of the mine or the converse migration from the general atmosphere into the area behind the stopping (dam).

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COMMUNIQUÉ TECHNIQUE AU SUJET DE LA CONSTRUCTION DE DISPOSITIFS D'ARRÊT OU DE BARRAGES À LA HOUILLÈRE DE SYDNEY

par

G.A. Haslett*

RÉSUMÉ

La communiqué technique que voici fait état des raisons pour lesquelles des dispositifs d'arrêt ou des barrages sont construits.

Quelles que soient les raisons sous-jascentes à la construction de dispositifs d'arrêt ou de barrages à l'intérieur des mines de charbon souterraines, les seules normes de construction acceptables sont celles qui assurent une protection adéquate en cas d'explosions. Ces dernières peuvent se produire derrière tout dispositif d'arrêt ou barrage à l'intérieur des vieux travaux obturés qui ne sont plus accessibles. Les dispositifs d'arrêt ou barrages doivent également être scellés pour empêcher toute entrée d'air ou de gaz se trouvant derrière le dispositif d'arrêt (barrage) dans l'atmosphère de la mine ou inversement, l'entrée d'air et de gaz de l'atmosphère de la mine dans la zone qui se trouve derrière le dispositif d'arrêt (barrage).

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INTRODUCTION

The nomenclature of underground coal mining where English is spoken is confused by the use of a great number of different terms which have a common meaning. The use of these terms has depended on the development of dialects and colloquialisms that have reflected the past isolation of some communities.

For the purposes of this technical note stopping or dams are installed in underground coal mines to seal off in an effective manner the workings beyond and behind the site where the stopping or dam is constructed. The process of sealing off should effectively exclude the intrusion or the extrusion of the internal or external atmospheres or gases. The stopping or dam must also contain any explosion that might occur within the workings beyond and behind the stopping or dam.

Stoppings or dams are sometimes constructed because of the incidence of heatings (incipient spontaneous combustion) or for the isolation of active fires. In such circumstances it is necessary to utilize adequate available material in order to comply with a requirement for haste, and then to consolidate at a later stage when control has been imposed with either the reinforcement of the stopping (dam) or the construction of a more adequate stopping (dam).

Should there be a need to reenter the zone beyond and behind the stopping (dam) for purposes such as the recovery of bodies or equipment or for a reexamination of the workings for potential for their further working, then an explosionproof tunnel can be incorporated into the stopping (dam). Such explosionproof tunnels do not destroy the integrity of the stopping (dam) but allow access behind it by rescue teams wearing self-contained breathing apparatus for the purposes of reconnoitring and determining the potential for reopening the section beyond the stopping (dam).

A brief account of a stopping procedure that was used in Australia and the U.S.A. is given with the reasons underlying the adoption of the procedures. A review of the guidelines for the contstruction of stoppings (dams) in the Federal Republic of Germany (F.R.G.) and in the United Kingdom (U.K.) then follows.

There are marked disimilarities between the layouts of the mines within the Sydney Coalfield with those of the U.S.A. and Australia. Some similarities between the layouts and conditions of the mines within the Sydney Coalfield with those in F.R.G. and the U.K. are noted.

A STOPPING PROCEDURE USED IN AUSTRALIA (1)

Aberdare Colliery located near the town of Cessnock, N.S.W. Australia was opened in 1907 and worked continuously since its opening until the working was interrupted by a heating that developed into an active fire.

It became evident on November 6, 1975 that there was a goaf heating in the west section of the mine where depillaring with a continuous miner was taking place. Draeger tube readings indicated a concentration on the return side of the heating of five parts per million of CO. A decision was made to seal off a part of the section with concrete wall blocks to exclude the entry of the atmosphere to the part where the heating was situated.

After three continuous working days of erecting seals it became evident from the CO readings taken on the return side, which had now reached levels of 3000 parts per million, that the heating had become an active fire. The CO readings were complemented by the presence of dense brown smoke and CH_4 readings to a level of 2.5%. No alternatives were left under such conditions but to withdraw from the mine leaving three of the entries to the fire zone without seals.

The need to stop off the mine became evident from the presence of low density black smoke in the fan drift with CO readings of 2200 parts per milion and CH_4 readings of 0.4%. Aberdare Colliery was generally considered to be a nongasy mine but a reading of 0.4% CH_4 in the fan drift was confirmatory of a level of 2.5% CH_4 taken previously in the return from the west side by a hand-held methanometer. The access to underground workings was available via two surface drifts and two vertical shafts all of which were sealed, the seals being completed by November 11. One drift and both shafts had sampling pipes installed to the levels of the underground workings by rescue teams during the sealing operations.

A decision was then made that any endeavour to recover the mine by rescue teams wearing self-contained breathing apparatus though practical would be too costly.

Following a trial at another colliery in the area of the placement of fly ash seal via a surface borehole, seven cased holes were drilled from the surface each of 140 mm dia (5.5 in.). Three holes were located to connect into those entries which were left unsealed and four - three to connect at points close to the seals and one to connect with the workings close to the site of the heating - were also drilled. The seals were completed by the injection of fly ash down each of three pipes at a pressure of 140 KPa (20.3 lb/in.^{2}). The other four holes were used for the purposes of observation using a television camera encapsulated in a 130 mm (5.1 in.) steel cylinder to view and give confirmation of the completion of the seals and to observe the conditions in the area of the heating. The length of the three holes drilled to inject the fly ash was 145 m (476 ft) and the amounts of fly ash injected were respectively 546 tonnes, 442 tonnes and 642 tonnes.

By mid-April 1976 the air analyses taken from the bottom of the fan drift indicated that the heating had not been active for a period of fifty days. A decision was made to recover the mine and ventilation was reestablished on May 31. Thereafter progressive recovery was made until the mine was brought in full operation by October 25, 1976. The recovery of the district where the heating occurred involved the boring of another two holes to the workings from the surface to emplace two further fly ash seals.

A STOPPING PROCEDURE USED IN THE U.S.A. (2)

The first sealing with fly ash in mines within the U.S.A. was undertaken with the assistance of the United States Bureau of Mines following a fire that occurred on January 14, 1974 at the Joanne Mine at Rachel in the state of W. Virginia.

The fire was attributed to electrical wiring. The experience gained in combatting this fire guided the subsequent control of the fire at Aberdare Colliery in New South Wales.

Air was excluded from the fire zone by the placement of six fly ash fire seals through six boreholes drilled from the surface. Twelve further holes were drilled one each side each of the fly ash seals for the purpose of observation. Sonar and television probing through these boreholes was made to ensure the proper location of the fly ash seals and their satisfactory completion. A power borehole already present from the surface to supply power underground was used to lower a tube bundle system into the mine as part of a 19-tube system used to monitor from this borehole with two additional tube bundles located at an air shaft. The system had facility for continuous monitoring of O_2, CO, CO_2 and CH_4.

Pumping of inert nitrogen diluted with air into the fire zone during sealing operations was also used for maintaining the O_2 concentration to levels of less than 10% because the CH_4 concentration within the fire zone contained over 30% CH_4.

Reventilation of the mine was reestablished after 155 days from the occurrence of the fire after readings at both points of installation of the tube bundle system indicated its extinction.

GUIDELINES FOR SEALING OFF AND DAMMING UP WORKINGS IN NORTH RHINE WESTPHALIA IN THE FEDERAL REPUBLIC OF GERMANY (3)

Guidelines for the construction of stoppings and dams within the F.R.G. were issued to their Mines Inspectorate in 1971. The guidelines intended to complement and explain the regulations contained in Sections 125 and 126 of the Coal Mining Regulations of the Regional Mines Inpectorate of the North Rhine Westphalia regarding the sealing off and damming up of mine workings.

Recommendations are given in these guidelines concerning the preparation of the walls at sites denoted dam sites should there arise a need to erect a dam at such a prepared site. The recommendation addresses the need to secure airtightness by securing the dam to prepared walls. After a dam has been installed acceptance testing has to be carried out at a period at latest fourteen days after its completion. Included in the acceptance tests are:

(a) a satisfactory state of the surrounding rock as well as the connection between the dam and the rock,

(b) measurements of the pressure gradient of the dam, i.e. the difference of static pressures between the outside face and the face at the back of the dam, and

(c) the effectiveness of the dam using smoke tubes to detect atmospheric migration around the dam.

If there is a risk that the airtightness/gas tightness or the resistance of a dam might be impaired by external influences, e.g. by the effects of mining, then monitoring of the dam must continue.

Additional measures are cited for individual cases of the extension of the thickness of an existing dam in order to improve airtightness. The suggested measures are the application of cementitious slurry (shotcrete) or rock dust or, where external applications would have no effect, then recourse to pressure grouting.

For the calculation of the length or thickness, whichever is greater, of an explosionproof dam in horizontal or inclined conditions and placed by pumping or other suitable means according to the material used for its construction, the following expression is to be used:

$$I_D = 0.865 \times a \times \left(\frac{q}{\sigma bz}\right)^{\frac{1}{2}} \qquad \text{Eq 1}$$

where I_D = length of the dam

a = maximum height or width, whichever is the larger, at the site of the dam after removing the lagging but without notching the rock walls to form dam abutments

q = static explosion pressure loading on the dam in N/mm^2

σbz = bending or tensile strength of the dam construction material in N/mm^2

The required length of dam necessary for a roadway supported by steel arches of dimensions of 4.88 m (16 ft) x 3.66 m (12 ft) that would have to withstand an anticipated explosion pressure of 0.7 N/mm^2 (7 bar on 101.5 $lb/in/^2$) and placed by pumped anhydrite would be:

$$I = 0.865 \times 4.88 \times \left(\frac{0.7}{4.81}\right)^{\frac{1}{2}} \quad \text{Eq 2}$$
$$= 1.61 \text{ m } (5.28 \text{ ft})$$

The value of the bending-tensile strength of the pumped anhydrite was obtained from Table 1 supplied as part of the guidelines in the F.R.G. Table 1 gives the name and address of all manufacturers in the Rhine Westphalia Area of the F.R.G. together with the proprietary name of suitable and approved dam construction materials manufactured by them. Anhydrite with a binder Bayer Anhydrite Binder AB20 was selected from the table for calculation of a dam length because it compares reasonably to Hardstop that is referred to later in the Schwarz Arley Emergency stopping that is a standard for stoppings with British Coal's Mine Rescue Services.

MEMORANDUM ON SEALING OFF FIRES UNDERGROUND PUBLISHED BY THE INSTITUTION OF MINING ENGINEERS IN THE U.K.

A committee of distinguished members of the Institution of Mining Engineers of the U.K. was appointed in 1962 to examine methods of sealing fires in underground mines. The terms of reference for the committee was to produce uniform standards of acceptable and proven methods for sealing off from such fires. The committee enquired extensively throughout the land on sealing off practices at mines and in their report (4) submitted in 1963 gave a number of standard examples of what, at that time, were considered good sealing practices. Figures 1 and 2 are two such examples copied directly from that report.

Fig. 1 illustrates an example of a stopping claimed to be explosionproof erected when it is anticipated that the stopping will not be reopened nor would there be any danger from explosion during sealing operations.

Table 1 - Approved dam construction materials for North Rhine Westphalia District

English Equivalent Name	Material/Manufacturer	Water/Solids Ratio	Bending-Tensile Strength	
			N/mm^2	$(lb/in.^2)$
Stopper	Dammer Anneliese Zementwerke AG, Neubeckum	0,45	1,28	(186)
Blitz Stopper	Blitzdammer	0,40	6,28	(911)
	Anneliese Zementwerke AG, Neubeckum	0,50 - 0,70	4,81	(697)
Special Gypsum	Bergbau Spezialgips D Gebr. Knauf Gipswerke, Iphoven/Main	0,7	1,57	(228)
Anhydrite Binder	Bayer-Anhydritbinder AB 20 - Bergbau (AmeA) Bayer-Anhydrit-Verkaufsge- sellschaft mbH, Leverkusen	0,36	4,81	(697)
Pumped Cement Mixture	Montapress Thyssen-Niederrhein-AG Abt. Zementwerke, Oberhausen	0,45	2,45	(355)
Backfill Mortar	Verfullmortel MS-CS	0,3	4,41	(639)
	Stocker-Beton GmbH,	0,4	2,45	(355)
	Duisburg	0,5	1,57	(228)
Dam Construction Mortar	Dammbaumortel DM1	0,30 - 0,32	4,3	(624)
	quick-mix	0,35	2,5	(363)
	Spezial-Trockenmortel Dorsten GmbH & Co KG	0,40 - 0,45	2,2	(319)

Table 1 (cont'd) - Approved dam construction materials for North Rhine Westphalia District

English Equivalent Name	Material/Manufacturer	Water/Solids Ratio	Bending-Tensile Strength N/mm^2 ($lb/in.^2$)		
			Mischung		
			1:1	2:1	3:1
Rock Dust/Cement	Gesteinstaub/Zement (HOZ 350 L)-Mischung				
	Gesteinstaub: gem. ß 224	0,36	3,34 (484)	2,06 (299)	1,86 (270)
	Abs. 1 vom LOBA NW	0,38	2,75 (399)	1,96 (284)	1,47 (213)
	zugelassene Qualitat	0,40	2,16 (313)	1,57 (228)	1,08 (157)
	Zement: Versch. Zementwerke				
Dam Construction Material	Dammbaustoff HT2	0,4	6,1	(885)	
	Anneliese Zementwerke AG, Ennigerloh I.W.	0,5 - 0,6	3,2	(464)	
Dam Construction Material	Dammbaustoff SD 1 SAKRET Produktionsges. Munsterland MBH + Co. KG, Munster	0,36 - 0,38	3,1	(450)	
	Spritzmortel SM 4 SAKRET-Trockenbaustoffe Siegert GmbH & Co. KG, Neuss	0,16 - 0,20	3,2	(464)	

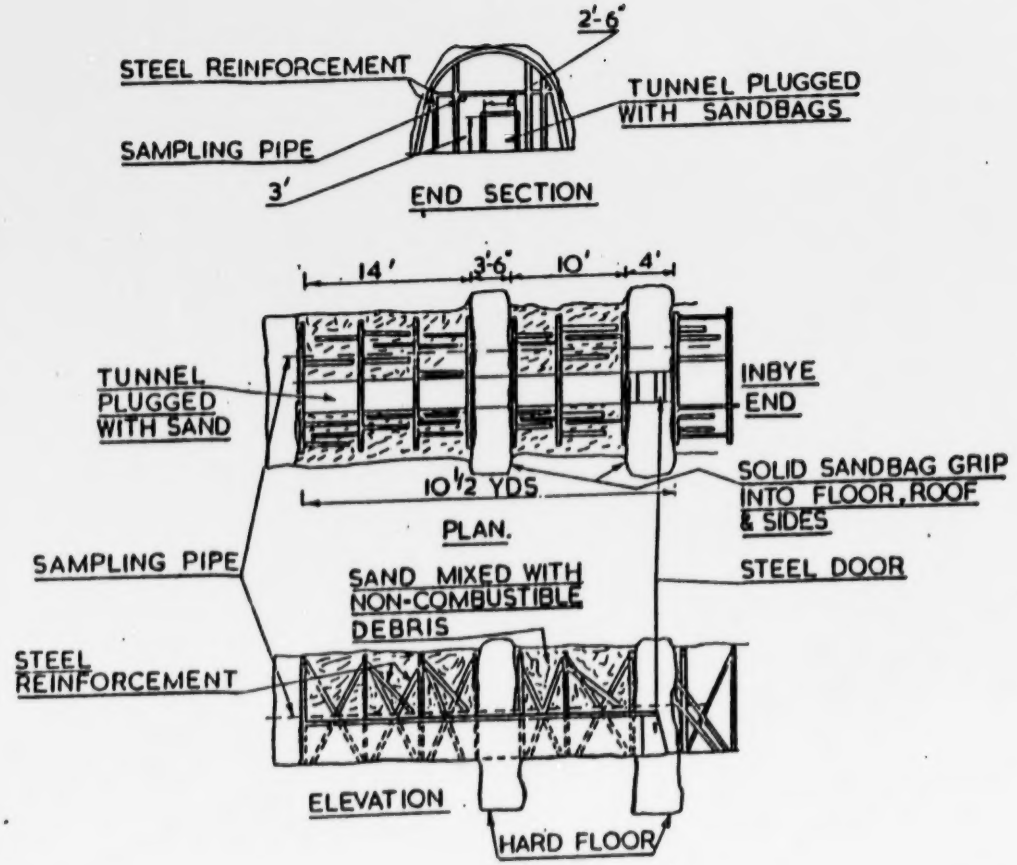

Fig. 1 - Explosionproof stopping where it is expected that the stopping will not be reopened and when there is no possibility of danger from explosion during sealing operations

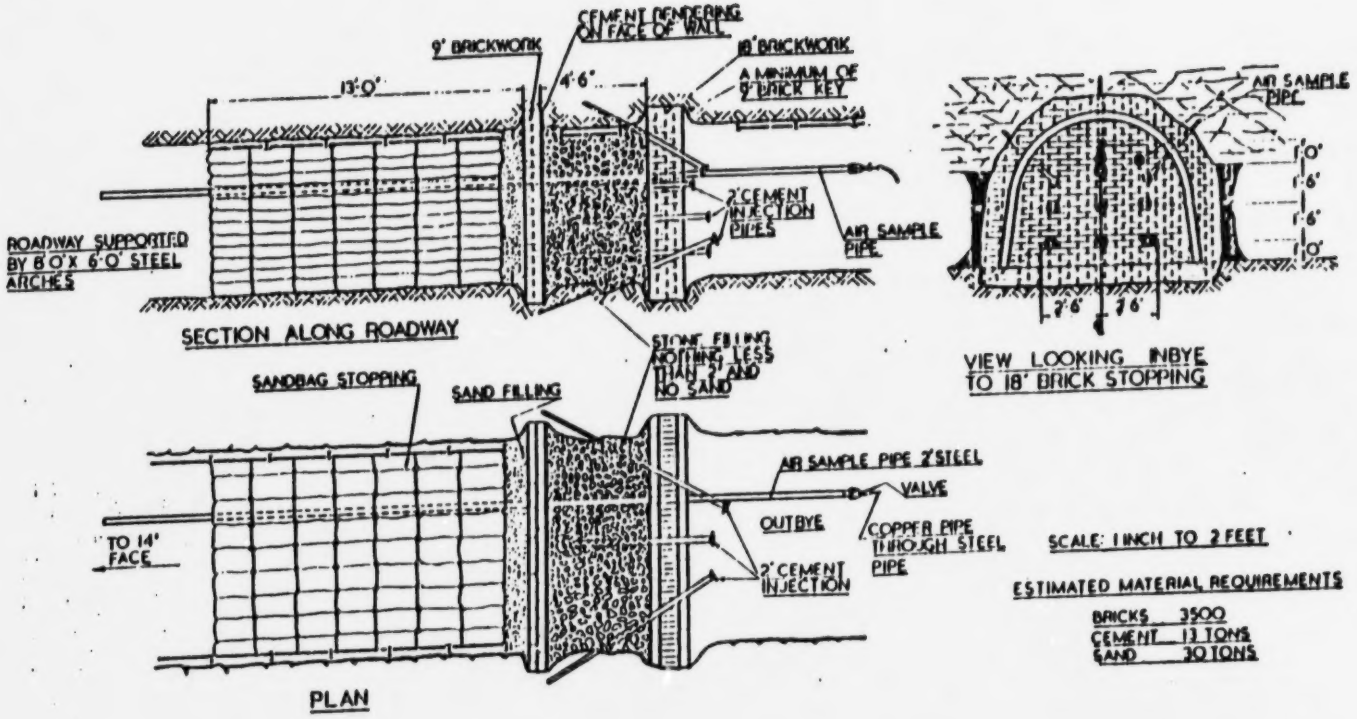

Fig. 2 - Explosionproof stopping erected in badly broken ground where it is not intended to reopen the district

The total length of the stopping was 9.6 m (31.5 ft). For an arched roadway of 3.96 m (13 ft) x 2.74 m (9 ft) its emplacement would comprise an estimated material weight of 104 tonnes of sand mixed with broken pit rubble (30% sand/70% rubble), 39 tonnes of sandbags and approximately 1 tonne of 102 mm x 102 mm R.S.J. section girders to a total weight of 144 tonnes. This exludes shuttering lumber which might raise the estimated weight by a further 0.3 tonnes.

The method of construction employed would be to erect a back shuttering of lumber with two or three spragging girders stamped into the floor and boxholed into the roof or sides and then fill the roadway in completely with a mixture of sand and broken rubble solidly to the roof to front shuttering for an approximate distance apart of 1.2 m (4 ft) - 1.5 m (ft). On completion the front shuttering would become the back shuttering for the next compartment to be completed. To exclude atmospheric migration, an intermediate sandbag plug would be installed keyed into the unfractured zones of rock at the roof, floor and sides. The erection would continue in this manner until the stopping would be completed by a final sandbag plug again solidly keyed into the floor, roof and sides and faced with a lumber facing. The benefit of such a method of construction was that it did not involve any skills additional to those of an ordinary miner.

The stopping illustrated in Fig. 2 provides an example of the construction details considered necessary where broken ground is prevalent and there is no intention of opening the district. The arch dimension shown is of a width 2.59 m (8 ft) x 2.29 m (7.5 ft). If the arch dimension were 3.96 m (13 ft) x 2.74 m (9 ft) as given in Fig. 1, the estimated material requirements would then have need to be amended to become:

BRICKS	6800 (11 tonnes)
CEMENT	26 tonnes
SAND	60.5 tonnes assumed dry S.G. of Sand = 1.7
+2" RUBBLE	16 tonnes at an assumed bulking factor of 2:1
BAGS	850 - 900

Such a stopping could not be erected in circumstances of an active heating or fire in any mine where CH_4 could be present because a tunnel through it is excluded from its construction. It would, for completion, require the additional skills of one or two bricklayers and a person who was familiar with the operation of grouting equipment.

NATIONAL COAL BOARD SCHWARZ ARLEY EMERGENCY STOPPING

The U.K. National Coal Board (NCB) Mines Rescue Service published in December 1978 a handbook that was circulated to all collieries. It was titled "Instructions for the Erection of the Schwarz Arley Emergency Stopping" (5). A recommendation was made by Mines Rescue Service that every colliery where heatings might occur should keep sufficient telescopic props, clips, hookbolts, galvanized pans, etc. necessary to form the end shuttering frames for the construction of two or three Schwarz Arley stoppings.

Mines Rescue Service as a central service would make available on an emergency basis a mixing tank together with a pump, to pump an anhydrite plaster material with a patent name of Hardstop to construct a Schwarz Arley type stopping or stoppings. An isometrical view of the Schwarz Arley stopping is illustrated in Fig. 3 taken from the handbook issued by NCB Mines Rescue Service.

The length of any such stopping was governed by the maximum height and width of such a stopping according to the expression:

$$L = \frac{W + H}{2} + 2 \text{ with all units expressed in ft (2)} \qquad \text{Eq 3}$$

where L = length of stopping
W = max width of roadway in which the stopping is installed
H = max height of roadway in which the stopping is installed

RECORD OF A STOPPING THAT WITHSTOOD A SEVERE EXPLOSION

An account of a heating that occurred in October 1970 in the Haigh Moor Seam at Thurcraft Colliery, South Yorkshire in the U.K. was given in the June 1972 edition of the Mining Engineer (6).

This heating developed into an active fire. After stoppings were put on to seal the fire, an explosion occurred behind the stoppings. The severity of the explosion was such that it destroyed a well constructed air crossing on the return side of the face. A total of 260 m of roadway had

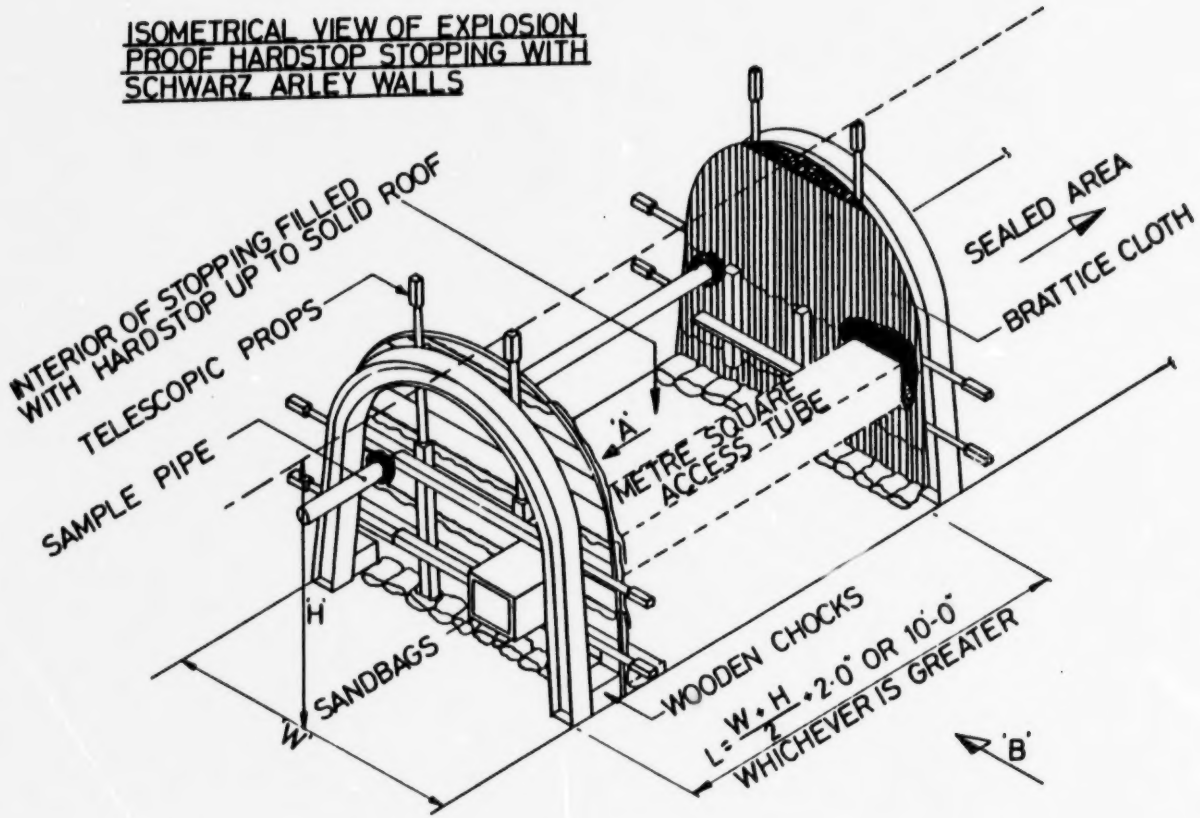

Fig. 3 - Schwarz Arley Stopping as illustrated in National Coal Board Mines Rescue Service Handbook

collapsed on the return side due to displacement of the steel arches by the force of the explosion. The return side stopping nevertheless remained intact and contained the explosion.

Details of this stopping are given in Fig. 4. It was constructed during the ongoing development of the heating to an active fire by regular colliery personnel with rescue teams equipped with self-contained breathing apparatus operating on standby.

The construction method and materials were sandbags filled with a sand and rubble mix reinforced by girders set as sprags stamped into the floor and set to the roadway sides. The dimension of the return roadway was a splayed arch section of a width of 3.65 m (12 ft) x 3.04 m (10 ft). The length of the stopping was 8.53 m (28 ft). The estimated weight of material contained in the stopping on an assumed bulking factor for the broken rubble of 2 with 30% dry sand mix would be 120 tonnes.

DISCUSSION

Table 2 gives details of the population density in each of the countries considered. The details were abstracted from the annual report of the United Nations Organization for 1987.

Table 2 - Population density

Country	Population (millions)	Surface Area km^2 (millions)	Population Density Persons/km^2
Australia	15.4	7.687	1.9
Canada	24.9	9.976	2.4
U.S.A.	234.5	9.363	11.7
U.K.	55.6	0.244	229.1
F.R.G.	61.4	0.249	246.3

From the table it can be observed that Australia and Canada have the lowest densities of population within the Western World with the U.S.A. occupying the third place.

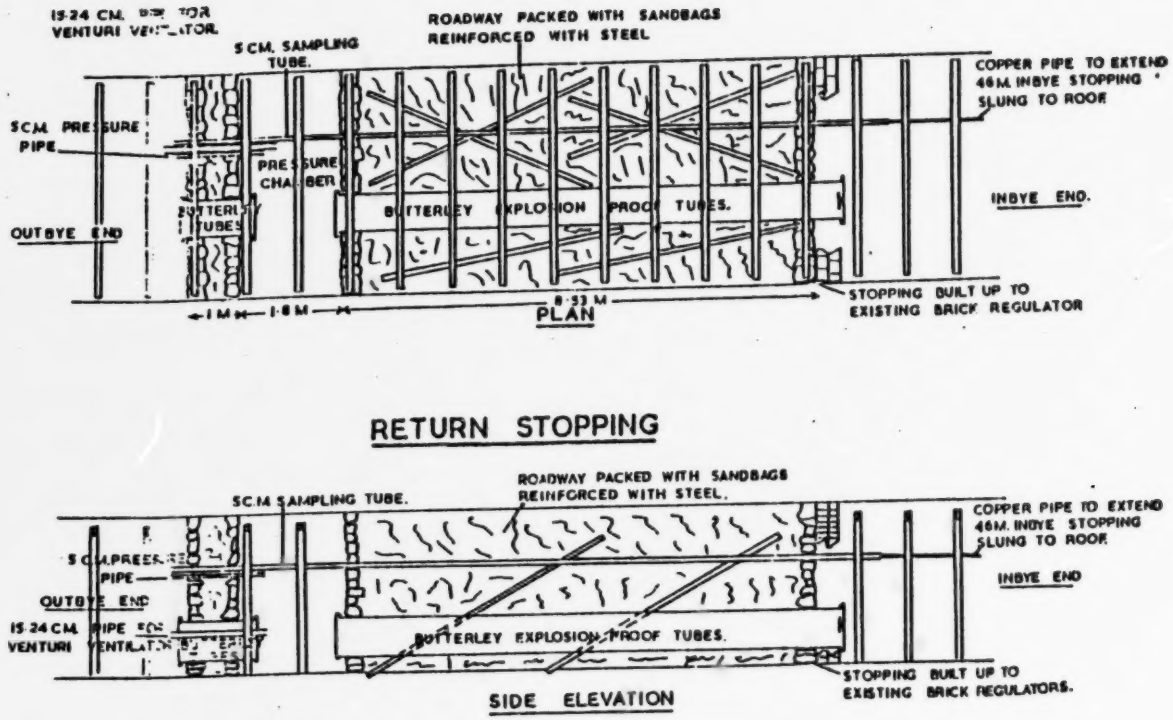
5 CM. SAMPLING TUBE.
ROADWAY PACKED WITH SANDBAGS REINFORCED WITH STEEL
COPPER PIPE TO EXTEND 46M. INBYE STOPPING SLUNG TO ROOF
5 CM. PRESSURE PIPE
PRESSURE CHAMBER
INBYE END.
OUTBYE END
STOPPING BUILT UP TO EXISTING BRICK REGULATOR
1 M
1·8 M
8·33 M
PLAN
RETURN STOPPING
5 CM SAMPLING TUBE.
ROADWAY PACKED WITH SANDBAGS REINFORCED WITH STEEL.
COPPER PIPE TO EXTEND 46M. INBYE STOPPING SLUNG TO ROOF
INBYE END
OUTBYE END
BUTTERLEY EXPLOSION PROOF TUBES.
STOPPING BUILT UP TO EXISTING BRICK REGULATORS.
SIDE ELEVATION

Fig. 4 - Return side stopping in the Haigh Seam at Thurcroft Colliery

Consideration of the concentration of much of the populations of these three countries within and around their large cities and in the surrounding areas leads to a conclusion that outside such conurbations there must be vast open tracts of land under which most of the underground coal mining operations take place. The possibility of access to and the drilling of vertical boreholes into such workings seldom present any problems. The advantages of vertical boreholes are that free flowing materials such as dry fly ash or dry sand can easily be placed, as can remote sensing and monitoring equipment, much closer to an incident than when the fighting of a fire has to be conducted from underground.

The U.K. and F.R.G. have population densities in persons/km^2 95.5 and 102.6 times greater than that of Canada. The possibility under such circumstances of sealing off a fire remotely is reduced proportionately. Considerations of access because of the presence of buildings, plant, railways, motorways, canals and the spoilage of crops on a concentrated agriculture industry are always present.

Heatings, fires and explosions are mostly combatted within the U.K. and F.R.G. by regular underground colliery personnel with rescue teams on standby or on active operation. Inevitably in each incident there are logistical problems and exposure of people to sometimes high levels of risk.

The coal mines within the Sydney Coalfield presently constitute the major part of the operational underground coal mining industry within the general context of the more recent past and probably the future underground coal mining operations within Canada during the next decade. They nevertheless remain anomalous because of submarine operations which denies any access to the workings from the surface. The techniques employed for combatting fires or explosives should they occur, must therefore have many common features with practices in the U.K. or F.R.G.

Table 3 summarizes the properties already previously outlined in this report of some of the construction materials and properties of stoppings and dams built in the U.K. or the F.R.G. To have relative consistency for the purposes of comparison, Table 3 relates all material requirements and dimensions to an internal roadway dimension of a splayed steel arch of a width of 4.88 m (16 ft) by a height of 3.66 m (12 ft).

Table 3 - Properties of the construction materials, stoppings and dams in the U.K. and F.R.G.

Length of Stopping or Dam metres (feet)	Materials Used for Dam or Stopping Construction	Total Weight of Materials Used in Construction of Stopping or Dam (tonnes)	Resistance to Explosions Bar (lb/in.^{2})	Origin of Design
(1) 1.61 m (5.28 ft)	Pumped anhydrite	76	Resistant up to 7 Bar (101.5)	Guideline to Inspectors of North Rhine Westphalia, F.R.G.
(2) 25.3 m (83 ft)	Sand/rubble mix in sandbags, wooden shuttering frames spragging girders	380	Unknown	General past practice in U.K.
(3) 15.3 m (50 ft)	Brick, cement, sand, sand/rubble mix in sandbags	300	Unknown	General past practice in U.K. for stoppings in broken ground
(4) 4.87 m (16 ft)	Pumped anhydrite	230	Resistant to values beyond 12.5 Bar (180) if constructed to precise standards	Mines Rescue Service (U.K.)
(5) 21.2 m (70 ft)	Sand/rubble mix in sandbags spragging girders	294	Withstood severe explosion	Dictated by emergency at Thurcroft Main Colliery, U.K.

The F.R.G. acknowledged in 1971 the use of plaster and cementitious materials for the rapid placement of stoppings by pumping. Such materials were used from the mid-60's for the placement of roadside packs within F.R.G. coal mines. The Mines Rescue Service of the U.K. acknowledged the utility of such materials and systems by the recommendation eight years later of the Schwarz Arley pumped stopping.

The guidelines and rules of each country do not seem, however, to be constant. Before crying foul on either country it might be rewarding to take a further look at the practices and the regulations of each.

Some of the seams that are worked in the North Rhine Westphalia district of the F.R.G. have a frequent incidence of heatings. The rescue organization sees a need to seal off quickly to bring a heating rapidly to a quiescent state. The guidelines as presented are for minimum standards. The discretion to uplift the standards is left to colliery management as they see fit in the light of experience.

Let it be assumed that a stopping is placed to a minimum standard and that after the mine has been evacuated for 24 hours the stopping is found to be intact on reentry into the mine by rescue teams. If beyond that the monitoring on resumption of normal mine operations required by regulation reveals that the stopping is not airtight, then remedial measures must be adopted up to physically increasing the length of the stopping if all other remedial measures fail. Conversely, let it be assumed that reentry has been made by rescue team members after a 24-hour period of evacuation to the site of the stopping to discover that an explosion has destroyed the stopping. The only alternative left is either the abandonment of the mine or the building of a more adequate stopping under conditions of greatly increased hazards.

The control of the water/solids ratio is critical to the values of bending-tensile strength of plaster and cementitious materials. The strengths are adversely affected by too greater or too little water contents. Control of the mix can only be precise if flowmeters are provided to accurately measure the volumes of both components.

The length of the Schwarz Arley stopping is approximately three times as great when compared with the minimum standards required within the F.R.G. for roadways of similar dimension (refer to Table 3). If the water/solids ratio is controlled precisely throughout the emplacement of such

a stopping, it would have the ability to withstand a static explosion of approximately 20.7 bar (300 lb/in.^{2}) when the anhydrite had set. If poor control of the water/solids ratio reduced the binding-tensile strength of the cured anhydrite to half maximum strength, the stopping could still resist a static pressure of 10.3 bar (150 lb/in.^{2}) which would provide an adequate safety factor against explosions excepting the least probable case of an explosion of an extraordinary violence.

The emplacement of a Schwarz Arley stopping for a roadway of similar dimensions and using similar equipment as is used in the F.R.G. would occupy a time three times as great in situations where shorter times can be critical to the safety of rescue personnel. The only redress would be to increase the mixing tank, pump, and pipe capacities. Contrary to such increases there might be imposed spatial limitations of the site.

CONSIDERATIONS ON THE RAPID CONSTRUCTION OF EXPLOSIONPROOF AIRTIGHT STOPPINGS OR DAMS UNDER CONDITIONS OF AN EMERGENCY

The first and best line of defence to combat an emergency is a constant state of preparedness for such an emergency. The state of preparedness for the construction of stoppings can only come from statements of a policy that must subsequently be strictly enforced. Such a policy must be based on practical considerations to include:

(i) individual site preparation for every stopping
(ii) the materials
(iii) the quality control of the materials
(iv) the mode of construction
(v) the strength of a stopping
(vi) the roadway dimensions in which the stopping is to be erected
(vii) the length of the stopping

Consideration of each of these items infer:

(i) A stopping will have a greater airtightness if it is constructed on a site where the roof sides and floor have been prepared. Such sites might from time to time need upgrading to maintain them to suitable standards.

(ii) If reference is made again to Table 3, past traditional practices have favoured the use of sandbags filled with dry sand or a dry sand -63.5 mm (-2.5 in.) pit rubble mix. The use of rockdust-filled bags particularly with paper bags does not provide sufficiently dense material, sufficiently uneven surfaces, nor a suitable coefficient of friction between each bag to make any stopping constructed with such materials explosionproof.

However, consideration of the length of the stoppings numbered (2) and (3) in Table 3 where rubble mix sandbags were used indicates that construction of these stoppings by manual labour would be both time consuming and arduous. For greater speeds of construction and a lesser probability of exhaustion of personnel pumped stoppings should be preferred.

(iii) Quality control has partially been covered in (ii), i.e. choice of bags and their contents. If pumped stoppings are to be considered, then the crews who operate such equipment must be familiar with its operation. A trial of Anhydrite for packing takes on a greater importance if similar methods will apply for the construction of stoppings. If such a trial is undertaken, it is important that standard samples are taken frequently and immediately from the pack for water content, curing and subsequent strength tests. Such tests will be beneficial in determining the standard deviation of the water/solids mix to arrive at a realistic value of bending-tensile strength and of compressive strengths for packs.

(iv) The mode of construction must include specific instructions for whatever type of equipment and materials that are to be used for the back and front shuttering of a stopping and for any intermediate shuttering frames essential to its completion.

A shuttering frame should have the qualities of practicality, a minimum number of parts, simplicity, effectiveness and ease of assembly and construction.

(v), (vi) and (vii)

From a given strength of material and a given roadway section an appropriate length of stopping can be derived.

A policy manual should be produced with adequate instructions, drawings and tables to cover clearly and concisely items (i) - (vii). Whatever policy is decided, adequate supplies of all materials and equipment to implement the policy effectively and rapidly under conditions of crisis must always be kept readily available. Designated stopping sites must inspected at regular intervals and be maintained in suitable conditions. Included in the policy manual must be provisions for the proper and regular training of adequate and suitable personnel.

CONCLUSION

The war diaries of Italy for World War II contained the following statement:

"Malta was the rock on which our hopes
in the Mediterranean foundered."

The British Imperial General Staff through habits of mental laziness that led to an inferred policy that the British always muddle through, never paid the attention to the defence of the island of Malta commensurate with its true value. This policy nearly cost the British the loss of Malta. It brought untold suffering to the inhabitants of that island and as crisis succeeded crisis brought the final relief of Malta to epic and costly proportions.

The assurance that when confronted with a crisis that a policy of muddling through will succeed is based on a principle of unfounded self-confidence. Self confidence in a crisis such as a fire underground is insufficient unless it is shared by every person who will be engaged in combatting it. The knowledge and assurance that the necessary equipment, knowledge and preparedness is available is of immeasurable importance.

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